Eulerian and Lagrangian Studies of Turbulent Transport in the Global Ocean

Synte Peacock (U. Chicago)

Frank Bryan (Nat. Center for Atmospheric Res.)

Tim Hall (NASA-GISS)

Rob Jacob (Argonne Nat. Lab.)

Steve Jayne (Woods Hole Oceanographic Inst.)

Mat Maltrud (Los Alamos Nat. Lab.)

Julie McClean (Scripps Inst. Oceanography)

Norikazu Nakashiki (Central Res. Inst. Electric Power Industry, Japan)

Kelvin Richards (U. Hawaii)

Luanne Thompson (U. Washington)

Darryn Waugh (Johns Hopkins)

Outline

- Scientific objectives
- Conceptual framework for experiments
- Challenges in modeling ocean circulation and material transport
- Computational tools and experimental design
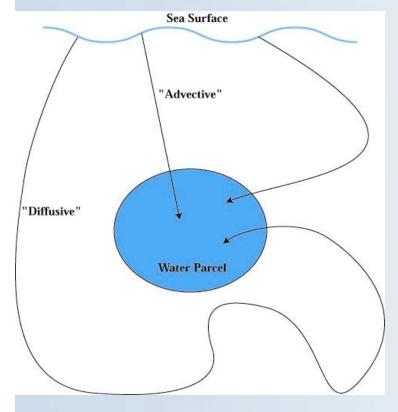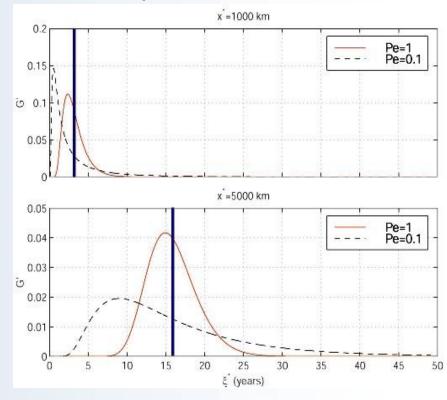- Analysis plans

Scientific Objectives

- At what rate and and by which pathways will material entering the ocean at its surface be distributed through its interior?

- What are the relative roles of the broad-scale time-mean flow, small-scale structures in the mean flow, and turbulent eddies in transporting material through the ocean interior?

- Are current estimates of the ocean uptake by radiatively important anthropogenic trace-gases biased by an incomplete representation of ocean turbulent transports?

Conceptual Framework:
Transit Time Distributions (TTDs)

• Also known as "age spectrum" or "transit time PDF"

• Concept commonly used in hydrology, upper atmospheric research

• Describes the probability that a fluid element has been in the flow for a certain amount of time since last having been in contact with the surface.

1-D Exampl:e Advection-Diffusion

(figure from Khatiwala et al., 2000)

Conceptual Framework: Formulation

The general solution to

$$(\frac{\partial}{\partial t} + L)C = Q$$

at some point x in the ocean interior is
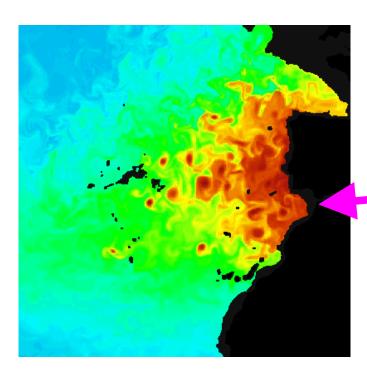
$$c(x,t) = \int_0^t c(x_0, t - t_0) G'(x, x_0, t') dt'$$

For a statistically stationary transport operator → boundary propagator can only depend on time through $\xi = (t - t')$. Also assume a tracer BC on Ω independent of position → $C(x_0, t') = C_0(t)$
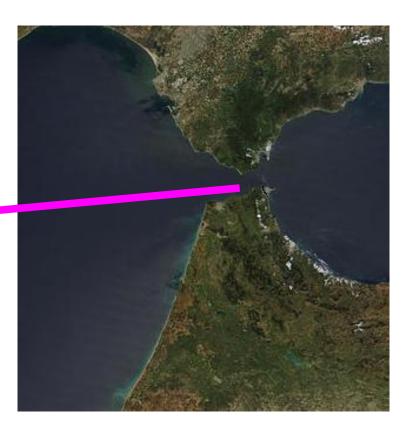
$$c(x,t) = \int_0^\infty c_0(t - \xi) G'(x, \xi; \Omega) d\xi$$

Concentration of tracer in surface ocean
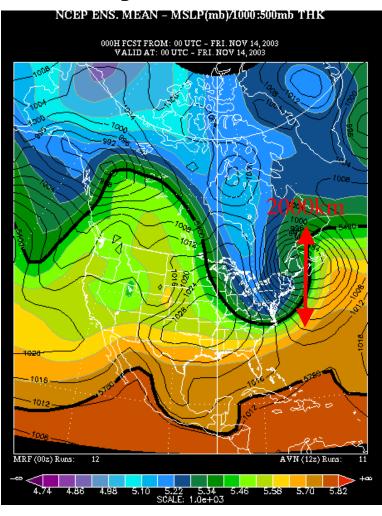
TTD

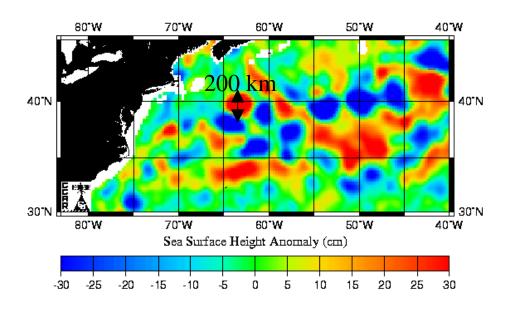# Challenges: Complex Geometry

Salinity at 1000m

Strait of Gibraltar

Challenges: Transient Eddy Scales
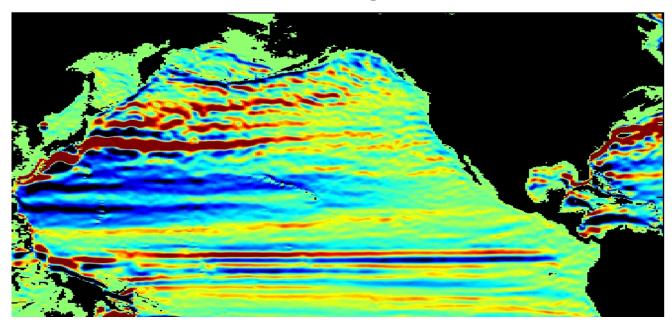
Atmosphere: O(1000 km)

Ocean: O(100 km)

Challenges: Time Mean Flow Scales

- Boundary layers in each direction
- Zonal jets in interior

mean u @ 400m

Richards et al (2006) GRL

Computational Tools

- Parallel Ocean Program (POP) developed at LANL
- Navier-Stokes equations for stratified flow on rotating sphere with hydrostatic and Boussinesq approximations
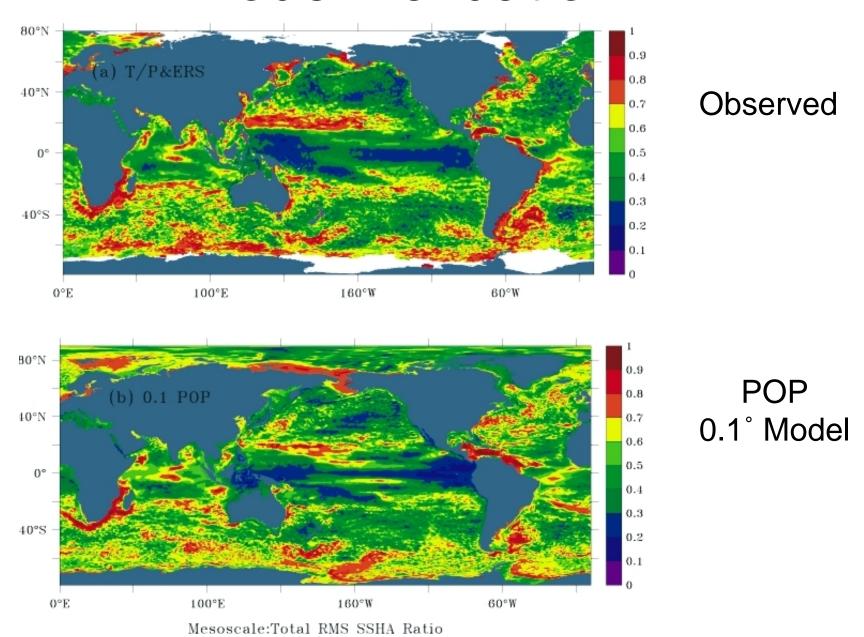- Global tripole grid: 3600x2400x42

Experimental Design

- 100 year simulation with repeating synthetic year forcing

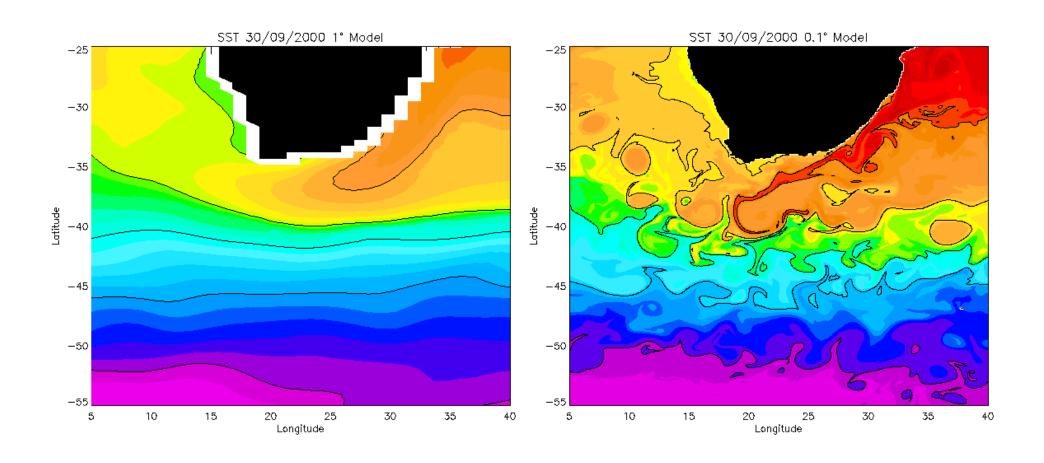|	Year 1-25	Year 26-50	Year 51-75	Year 76-100
1	CFC-11			CFC WOCE era ensemble
2	Global δ-fnc TTD			
3	Ideal Age			
4	Quadratic source tracer			
5	N. Atlantic Tile 1		S. Ocean Tile 1	
6	N. Atlantic Tile 2		S. Ocean Tile 2	
7	N. Atlantic Tile 3		S. Ocean Tile 3	
8	N. Atlantic Tile 4		S. Ocean Tile 4	
9	Simulated Floats (ARGO and SVP)			
10	Simulated Floats (Dispersion Statistics Clusters)			

Analysis Projects

- Model validation against available hydrographic, tracer and remote sensing observations
- Tracer uptake studies using derived TTDs
- Water mass provenance using regional TTDs
- Internal modes of unforced ocean variability
- Assessing mixing parameterizations in coarse-mesh models through comparison of TTDs
- Observing system design and assessment
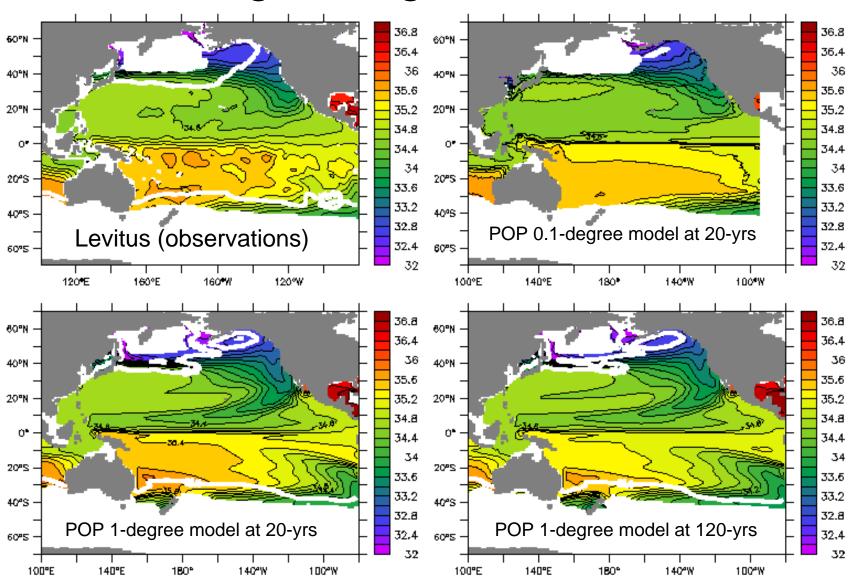- Analysis of mixing processes through simulated particle dispersion

Model Validation

(a) T/P&ERS

Observed

(b) 0.1 POP

POP
0.1° Model

Mesoscale:Total RMS SSHA Ratio

How Do We Compare the Transport Processes in Eddy-Resolving and Eddy-Parameterized Models?

SST 30/09/2000 1° Model

SST 30/09/2000 0.1° Model

Assessing Mixing Parameterizations

Levitus (observations)

POP 0.1-degree model at 20-yrs

POP 1-degree model at 20-yrs

POP 1-degree model at 120-yrs
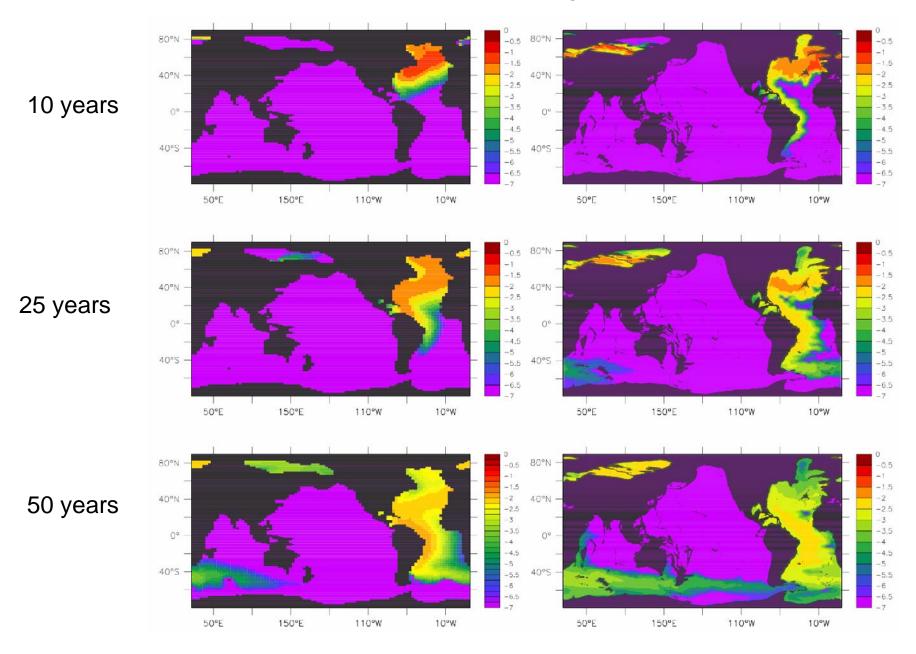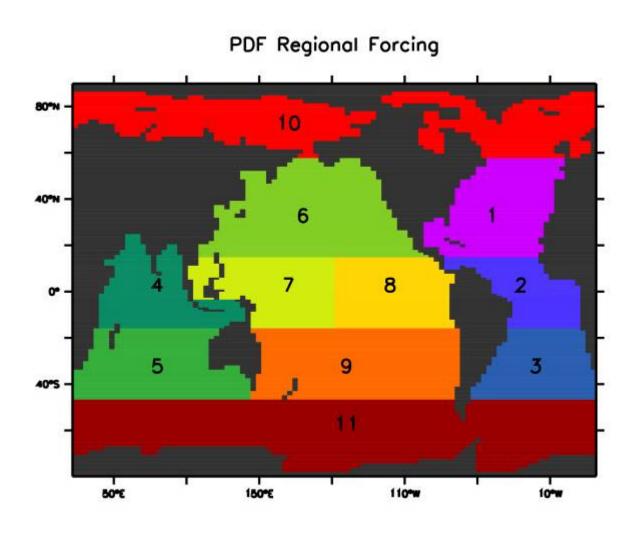
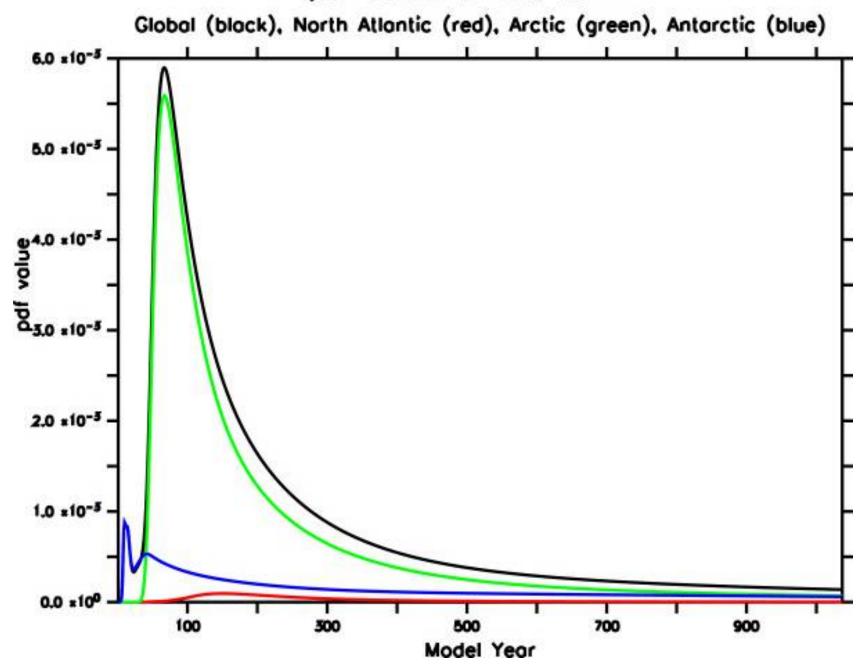Salinity of sigma0=25.6 isopycnal surface (courtesy Wei Cheng)

The importance of resolution: Does simulated TTD look different at higher resolution?
Compare 3° and 0.4° results for North Atlantic regional TTD at 2000m depth

10 years

25 years

50 years

Water Mass Provenance

PDF Regional Forcing

pdf at 30W, 40S, 2014m

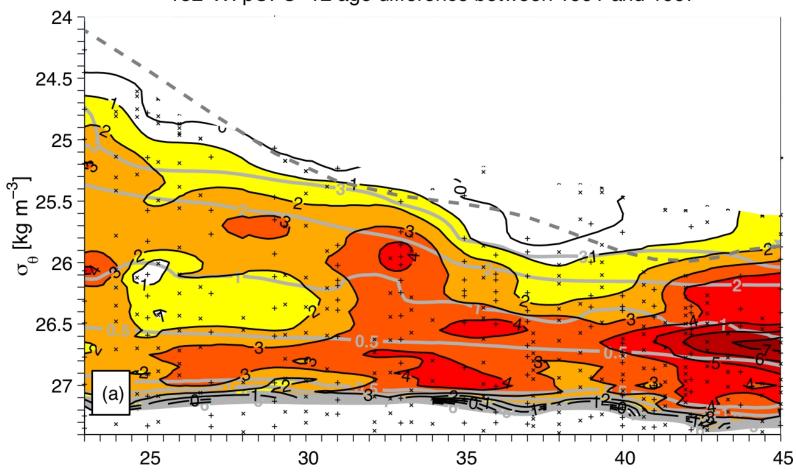Global (black), North Atlantic (red), Arctic (green), Antarctic (blue)

Observing System Design and Assessment

QuickTime™ and a
TIFF (Uncompressed) decompressor
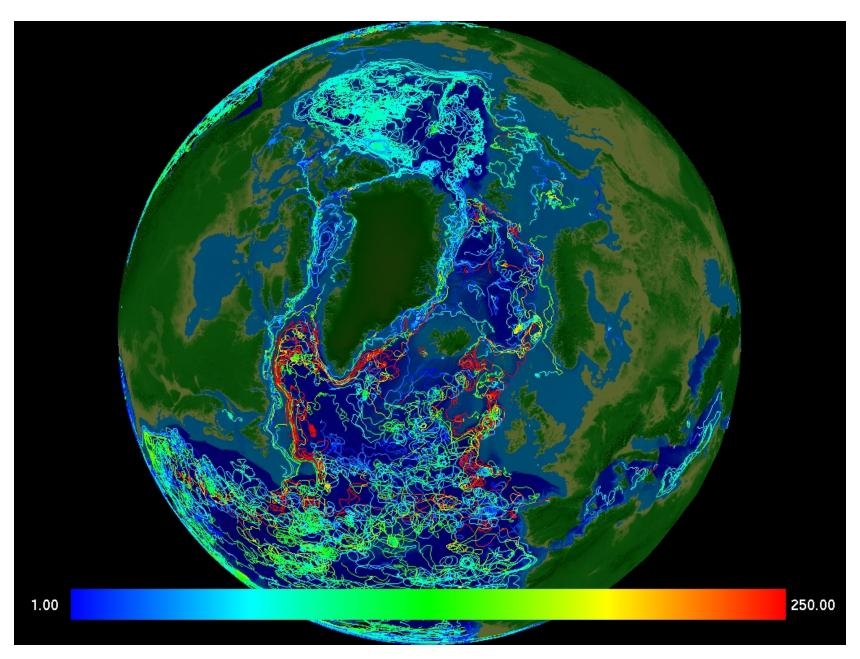are needed to see this picture.

Observed Change in CFC Age

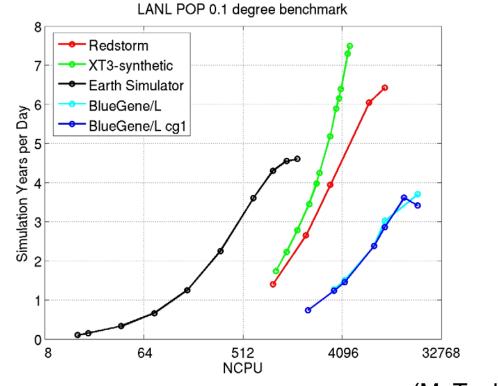152°W: pCFC–12 age difference between 1991 and 1997

Mecking et al submitted to DSR

Lagrangian Statistics

Code Performance & Development

LANL POP 0.1 degree benchmark

(M. Taylor, Sandia)

- New features for this project:
  - Monotonic advection
  - Anisotropic Gent-McWilliams closure
  - Efficiency improvements in barotropic solver

Outcomes

- Provide a bridge from the growing body of theoretical and process model based research on ocean transport to direct observations of the ocean.
- Provide quantitative metrics against which parameterizations of ocean mixing can be evaluated.
- Provide a means for evaluating the how representative past and current observing systems are, and aid in the design and optimization of future observing strategies.
- Provide a time series of unprecedented length with which to investigate the mechanisms for generation of low frequency variability of the ocean circulation.
- Set the stage for coupled climate system modeling using fully turbulent eddy-resolving ocean component models.